

## Stream temperature climate in a set of Southern Appalachian streams

Lloyd W. Swift, Jr. and Patsy P. Clinton  
*Coweeta Hydrologic Laboratory, SRS, FS, USDA*

**Abstract.** Water temperature patterns are described for five streams on forested watersheds in western North Carolina as part of stream monitoring in the Wine Spring Ecosystem Management Area. Elevation ranged from 918 m at Nantahala Lake to 1660 m at Wine Spring Bald with four temperature measurement sites located between 1145 m and 1200 m elevation, and one site at 925 m. Summer daily maximums were relatively constant, 13 to 16 °C; whereas, winter minimums ranged from 1 to 8 °C. These streams are subjected to a daily temperature range of 0 to 1 °C in the summer, 1 to 2 °C in the fall, 1 to 3 °C in winter, and 1 to 5 °C in the spring. Summer precipitation events did not always appear to affect stream temperatures but winter storms may have raised daily minimum temperatures. Water temperature responded to major fluctuations in air temperature and solar radiation more consistently than to precipitation input. In winter, stream temperatures increased an average of 0.3 °C with decreasing elevation from 1200 m to 1145 m. In late summer and fall, stream temperatures increased by 1.2 °C as elevation decreased from 1145 m to 925 m. However, in winter, the larger stream at 925 m was as cold as the smaller stream at 1200 m. From November through April, water temperatures in one branch of the stream system, draining a south facing slope with shallow soils, were 0.6 to 1.5 °C warmer than those in an adjacent stream at the same elevation.

### Introduction

The stream systems of the Southern Appalachians are a characteristic of these humid, well-watered slopes as well as one of the major assets of the forested ecosystem. In addition to being a significant part of the landscape, streams are the habitat for a large number of plant and animal organisms. Knowledge of the physical characteristics of these waters is an asset for the manager and investigator. Southern Appalachian streams are known as a "cold-water fishery", thus water temperature is a key parameter describing the stream habitat. Studies have focused on water temperature changes associated with forest cutting (e.g. Greene, 1950; Hassler and Tebo, 1958; Swift and Messer, 1971; Swift and Baker, 1973; Swift, 1983) but few reports have described the water temperature climate of the stream habitat in terms of seasonal and daily cycles and range and the links to driving forces such as precipitation, air temperature, and topography. Most habitat studies have focused on the environment of a specific set of organisms (Harshbarger, 1978; Peters et al., 1987; Stout et al., 1993; Tank et al., 1993; Webster and Waide, 1982). This

study describes in detail the water temperature environment of five Southern Appalachian Streams over time scales of years to hours and space scales covering several elevations and topographic aspects.

## **Materials and methods**

### **Site description**

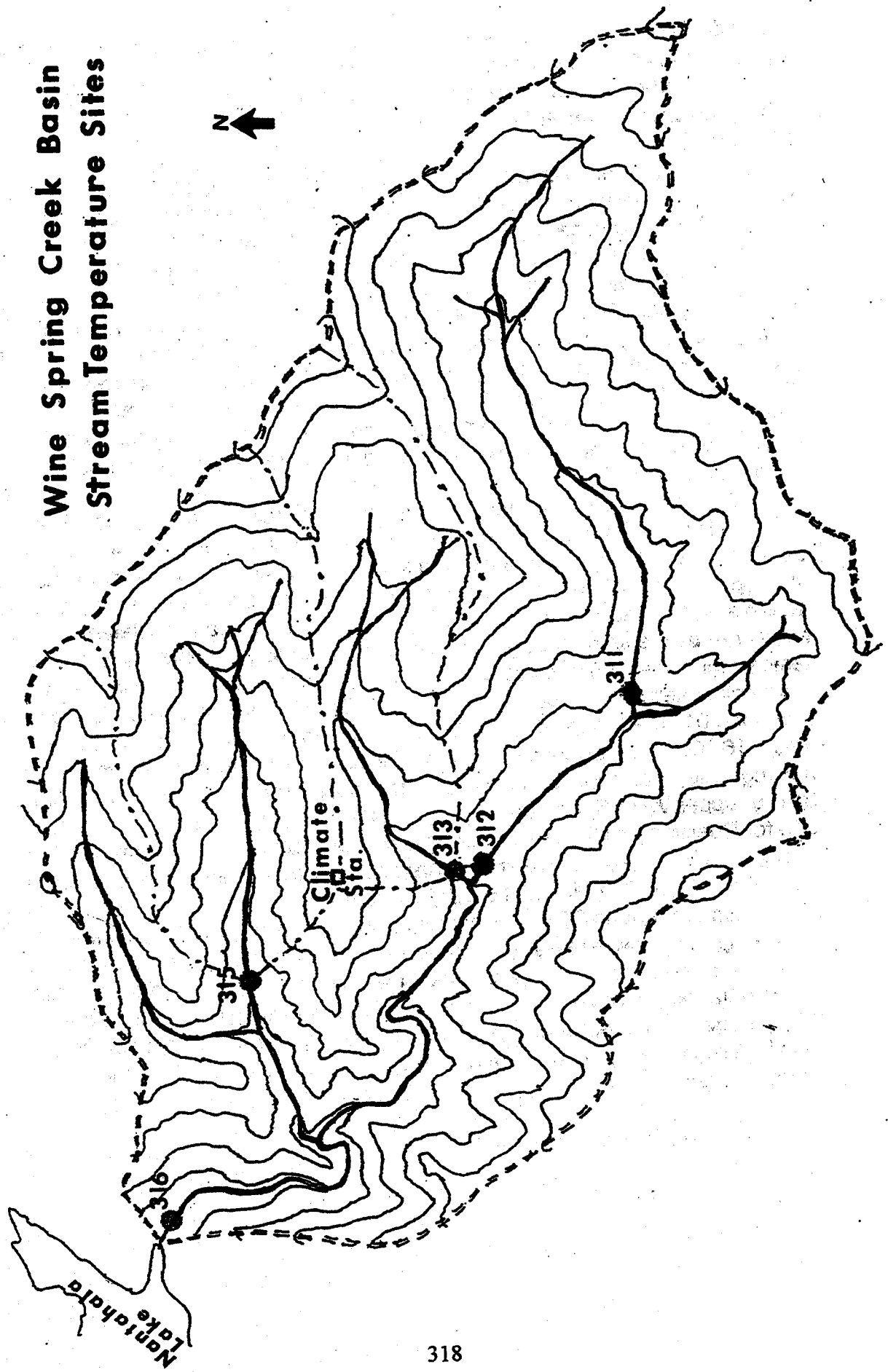
All measurements were made in the 1126 ha Wine Spring Creek Basin, a west-facing watershed of the Nantahala River drainage in Macon County, western North Carolina, U.S.A. The steep, forested slopes range in elevation from 918 m at Nantahala Lake to 1660 m at Wine Spring. Bald. The entire basin is managed by the Wayah Ranger District, National Forests in North Carolina, Forest Service, USDA for a variety of public uses. These include recreation, hiking, picnicking, camping, horseback riding, hunting and fishing, as well as the production of wood products. The stream system is dendritic with the headwater channel and three other streams all entering the main channel from the northeast (Fig. 1). Stream types range from A2 in the headwaters to A1 at several waterfalls and B3 in the lower-gradient bottoms (Rosgen, 1996).

### **Instrumentation**

Combination temperature sensors and data loggers (Onset Hobo-Temp model HTI-05+37) were installed at five sites on Wine Spring Creek and its tributaries. Each unit was submerged in a weighted waterproof case in shaded moving water. Each logger was retrieved for data recovery after approximately 42 days and replaced by a different logger, thus no site was consistently measured by the same sensor. The data loggers sampled and stored the temperature every 48 minutes. Daily mean, minimum, and maximum values were calculated from these observations. Temperatures were recorded to the nearest  $0.01^{\circ}\text{C}$  although the manufacturer-stated accuracy of the instrument was  $0.16^{\circ}\text{C}$ . The response time of the sensor in the case and submerged in moving water was about 20 minutes. The measurement sites were designated 311 for upper Wine Spring at 1200 m, 312 for middle Wine Spring at 1145 m, 313 for Bearpen Creek, 315 for Indian Camp Branch, and 316 for lower Wine Spring at 925 m (Fig. 1). Watershed area above each measurement point was 308, 504, 135, 172, and 1126 ha, respectively.

Climate Station CS301 was on a ridge, centered in the lower one-third of the watershed between Bearpen Creek and Indian Camp Branch valleys. Air temperature was sampled in a grassed opening every minute and summarized by the data logger into hourly means. Precipitation was collected in a standard 8-inch gage, measured weekly by dipstick. The chart trace from a nearby weighing recording gage was used to separate the standard gage amounts into storm and daily totals.

Fig. 1. Wine Spring Creek basin showing location of climate station CS301 and stream temperature sites 311 on upper Wine Spring Creek, 312 at middle Wine Spring Creek, 313 on Bearpen Creek, 315 on Indian Camp Branch, and 316 at lower Wine Spring Creek.



## Analyses

For most of these analyses, water temperature, air temperature, and precipitation were each reduced to daily values. In this report, the middle Wine Spring site was used as an index station, representing those phenomenon that were similar to ones at the upper and lower sites. Short periods of 1, 2, or 3 months were used to display typical seasonal or site relationships in more detail and to focus on specific stream temperature responses. Daily temperature range was the difference between the minimum and maximum observed for each day. As a measure of the day-to-day variability of water temperature, standard deviations of the daily means were calculated by months for each site. The temperature gradient for the three Wine Spring Creek sites was used to illustrate responses of water temperature to change in elevation. The temperatures in Bearpen Creek and Indian Camp Branch, each expressed as deviations from middle Wine Spring Creek, illustrate responses of water temperature to the contrasting topographies of those two side channels.

## Results

### Daily mean stream temperature

Figure 2 shows daily mean water temperatures at the middle Wine Spring site for 28 months and displays the seasonal range and an indication of the day-to-day variability. The monthly mean, averaged across all five streams, ranged from  $4.8^{\circ}\text{C}$  in January to  $14.6^{\circ}\text{C}$  in August (Table 1). At site 312, the lowest daily mean water temperatures for the year were about  $1^{\circ}\text{C}$  and lasted only 1 to 3 days in January or February. Mean winter temperatures ranged from  $4.9^{\circ}\text{C}$  at sites 313 and 316 to  $6.3^{\circ}\text{C}$  at site 315. The highest daily means at the middle site 312 were  $14^{\circ}\text{C}$  in 1996 and  $15^{\circ}\text{C}$  in 1995 and lasted for a much longer period during July through August. Mean summer temperatures ranged from  $13.5^{\circ}\text{C}$  at 315 to  $14.8^{\circ}\text{C}$  at 316. As will be shown later in more detail, day-to-day variability was much less in the summer season. The mean annual water temperature across all five streams was  $9.6^{\circ}\text{C}$  in 1995 and  $9.2^{\circ}\text{C}$  in 1996.

### Daily maximum and minimum stream temperature

The summer daily maximums at site 312 ranged from  $13$  to  $16^{\circ}\text{C}$  in July and August (Fig. 3). Year-to-year variation placed the warmest part of the summer in either July or August. The mean monthly maximum averaged for all five streams ranged from  $5.6^{\circ}\text{C}$  in January to  $15.0^{\circ}\text{C}$  in August. The mean monthly minimums ranged from  $4.0^{\circ}\text{C}$  to  $14.2^{\circ}\text{C}$  (Table 1). The winter minimum water temperatures had greater inter-day variation, about  $8^{\circ}$  spread over two months (Fig. 4) compared to the summer maximum spread of  $3^{\circ}$ . An element of the analysis for this report was to identify the causes for these periodic temperature excursions. The range between daily minimum and maximum values showed a seasonal effect, with the smallest ranges in summer and

Fig. 2. Daily mean water temperature recorded at Site 312 at mid Wine Spring Creek.

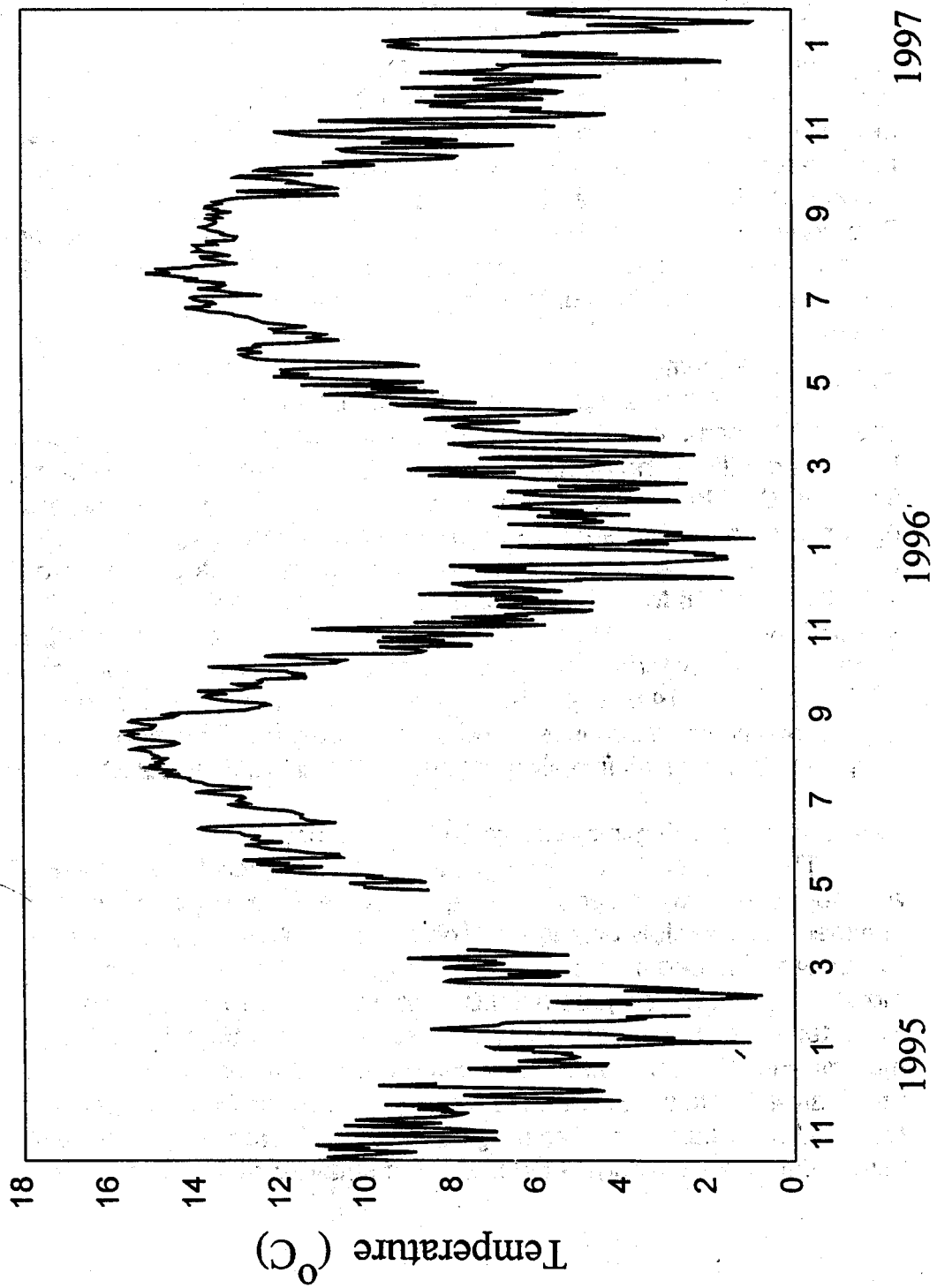


Fig. 3. Daily maximum water temperatures for two summers at Site 312.

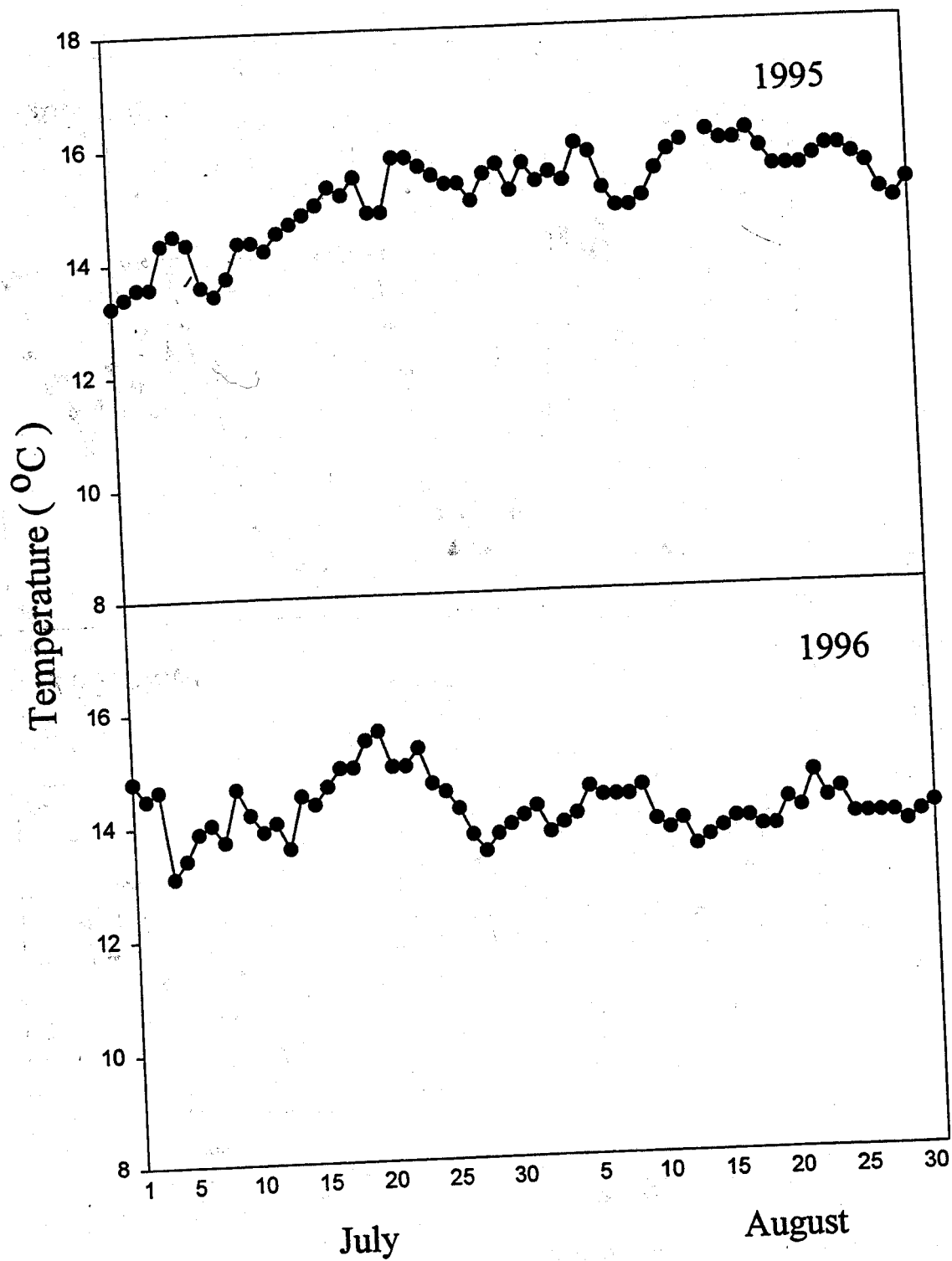
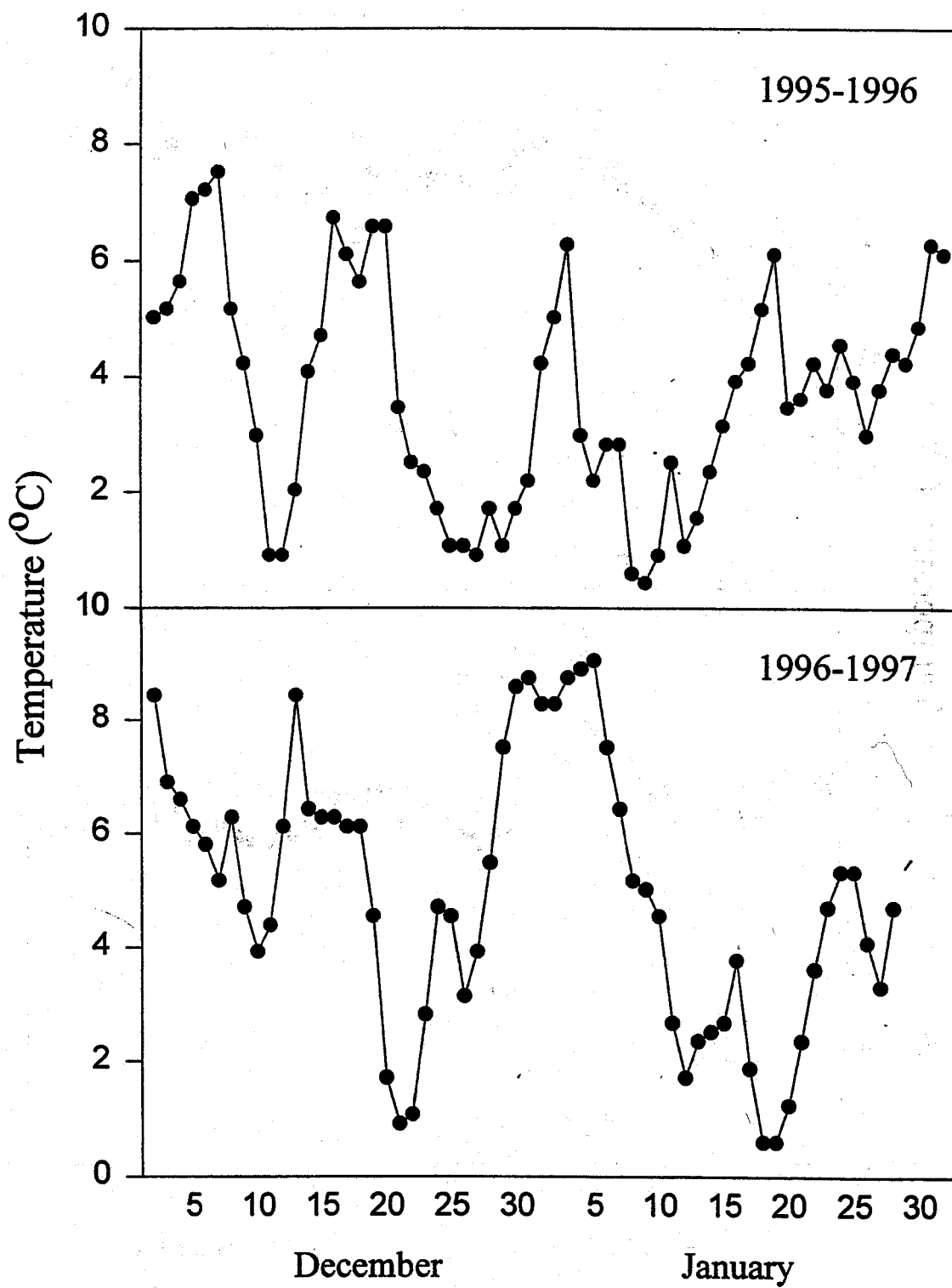


Fig. 4. Daily minimum water temperatures for two winters at Site 312.



gradually increasing daily range through fall, winter, to the greatest in spring (Fig. 5). The mean daily range for all sites was  $0.8^{\circ}\text{C}$  in August and  $2.8^{\circ}\text{C}$  in April. This phenomenon paralleled the forest canopy density, small daily ranges from mid-May to early October while the canopy is closed and larger daily ranges from mid-October to May when the leaves are off. The largest variation in daily range was in the spring when increasing solar radiation and warmer daytime air temperatures occurred without the forest canopy being fully developed. The standard deviations of the daily means ranged from  $0.4^{\circ}\text{C}$  in August and  $0.9^{\circ}\text{C}$  in June, July, and September to  $2.0^{\circ}\text{C}$  for December, January, and February and  $1.6^{\circ}\text{C}$  for all other months.

**Table 1. Ranked monthly minimum, mean, and maximum water temperatures ( $^{\circ}\text{C}$ ), averaged across five stream sites in Wine Spring Creek Basin for 31 months**

Month	Min	Mean	Max
Jan	4.0	4.8	5.6
Feb	4.4	5.3	6.2
Dec	5.0	5.7	6.4
Mar	6.1	7.1	8.2
Nov	6.5	7.4	8.2
Apr	7.1	8.5	9.9
Oct	9.1	10.0	10.7
May	10.5	11.4	12.3
Jan	12.1	12.6	13.2
Sep	12.3	12.8	13.3
Jul	13.8	14.2	14.7
Aug	14.2	14.6	15.0
1995	8.8	9.6	10.3
1996	8.4	9.2	10.0

#### Diurnal cycles of stream temperature

Continuous traces of all observations in a variable spring month and a summer month (Fig. 6) showed that the duration of the daily temperature peaks and minimums are short, probably 60 minutes or less. A complete diurnal cycle occurred most days but there were a few cases of relatively constant water temperature for 24 and rarely 48 hours. The solar radiation record at CS301 showed low energy input on April 8, 9, 13, 15, 19, 20, and 23 in 1996, dates where Fig. 6 shows a truncated diurnal cycle in the leafless season.

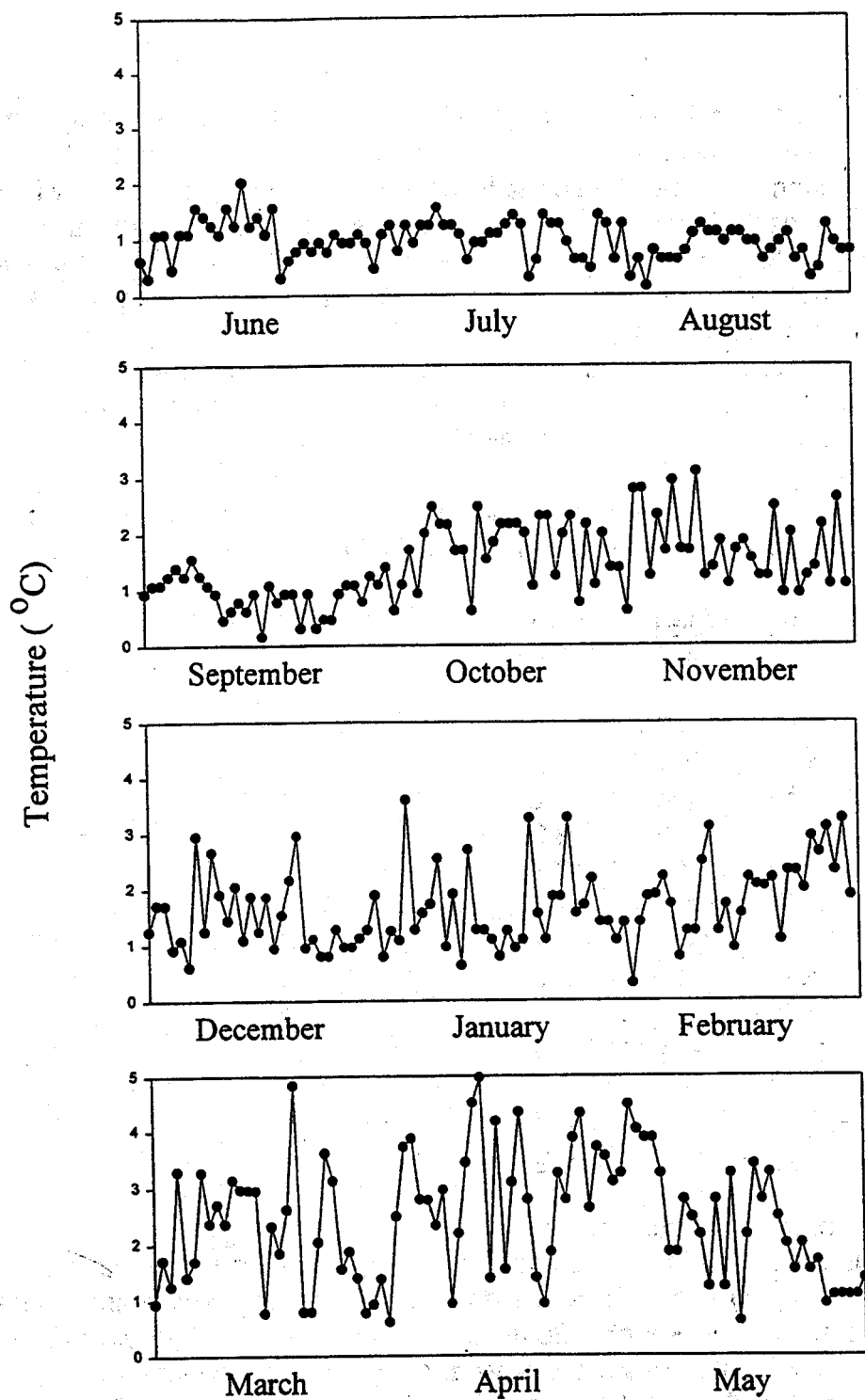


Fig.5. Daily ranges of water temperature for June 1995 through May 1996 at Site 312.

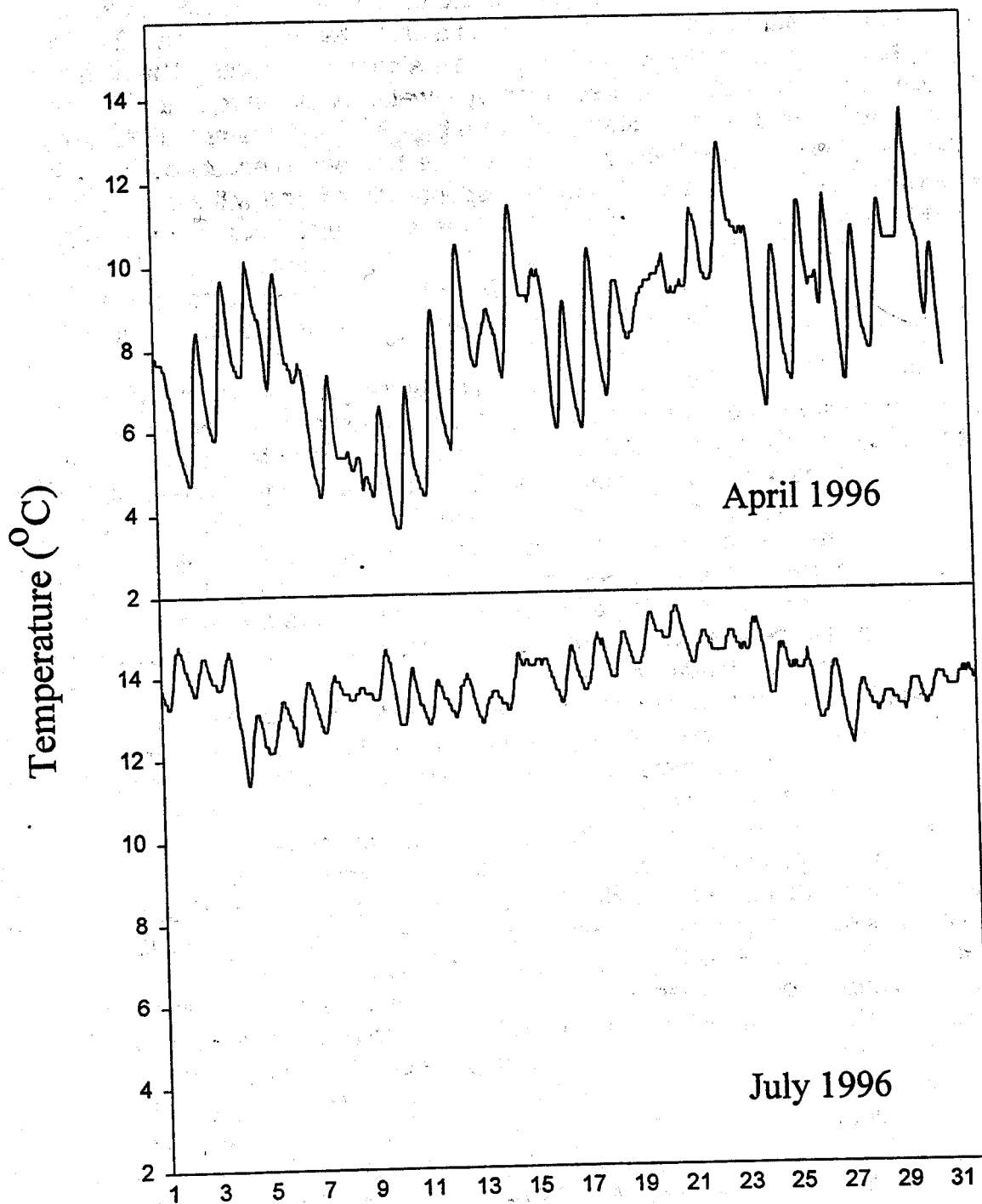


Fig. 6. Diurnal cycles of water temperature at Site 312 for a variable spring month and a more constant summer month based upon observations taken every 48 minutes.

### Effect of precipitation and air temperature

We expected that precipitation would have a different temperature than the groundwater that was feeding streamflow and therefore larger storms could modify the water temperature. The 47 mm storm of June 11-12, 1995 was followed by a water temperature decrease of a little over  $3^{\circ}\text{C}$  on June 12 to 14 (Fig. 7) but little response was seen after other storms that month. The 33 mm snow on January 5, 1996 was preceded by a water temperature drop, then an increase during and after the storm, followed by a  $3^{\circ}\text{C}$  water temperature drop on January 7 and 8. Another snow storm on the 18th also preceded a temperature decrease, although a large response did not follow the largest 102 mm rain on January 27. Fig. 8 showed that the water temperature for the same two months quite faithfully tracks the fluctuations of air temperature, including the warming during the January 5 snow. The  $17^{\circ}\text{C}$  drop in air temperature between January 18 and 19 was associated with a water temperature drop of  $2^{\circ}\text{C}$  at the same time.

Fig. 9 compares the diurnal water temperature traces shown in Fig. 6 with the diurnal cycles of hourly mean air temperature. Diurnal air temperature fluctuations were much larger than those for water, but water temperature does respond to the major shifts in air temperature in both the spring (leafless period) and summer. As expected, the water was cooler than air on all summer days and most summer nights. However, in a transitional period like spring, the stream was both warmer and cooler than air. Although the cloudy sky on April 8 truncated both air and water temperature cycles, low solar radiation on April 19 and 20 seemed to depress water temperature cycles more than air temperature.

### Effect of elevation and landform

Water temperature is expected to warm with decreasing elevation, possibly because air temperature is also warmer at lower elevations. Unexpected differences between water temperatures at the high elevation site (311) and the mid-elevation site (312) and between the mid-elevation and the lowest site (316) are shown in Fig. 10. Paired observations were subtracted such that an increased temperature over declining elevation would be a positive value. Although the temperature differences were small, less than  $2^{\circ}\text{C}$ , they do show increasing temperature as the stream dropped 45 m from 311 to 312 in the winter and 220 m elevation between 312 and 316 in the summer. However, the other two comparisons showed water temperature decreasing as the stream flowed downslope. The reasons for this dichotomy are under investigation. Omitting the mid-elevation site and subtracting the upper from the lower site temperatures produced a positive trend of  $1.1^{\circ}\text{C}$  in the summer and mixed results averaging  $-0.1^{\circ}\text{C}$  in winter. The daily water temperature range at the three elevations was plotted over air temperature in Fig. 11. The frequency of the larger daily ranges increased with elevation, i.e. the daily temperature

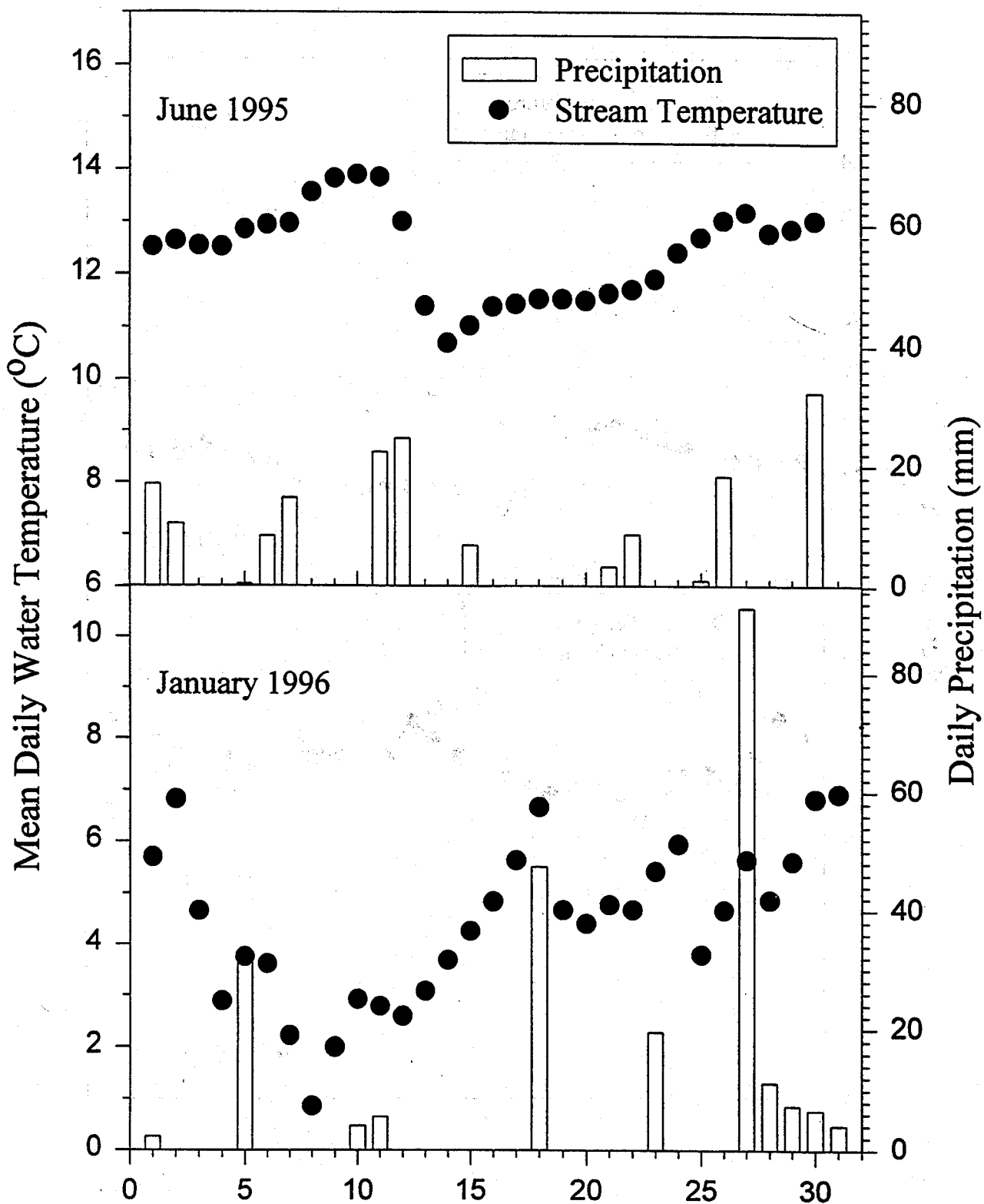
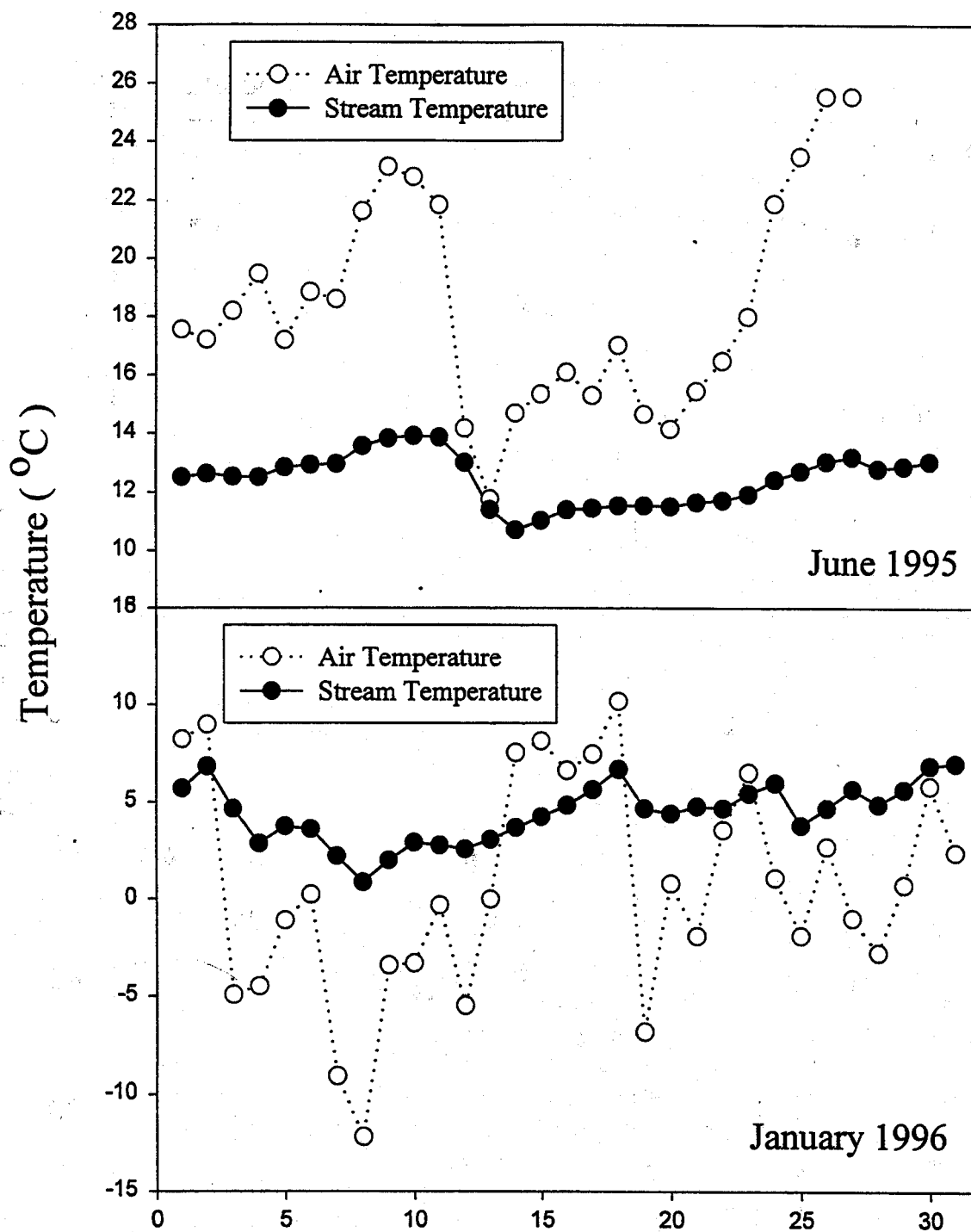


Fig. 7. Daily mean stream temperature at Site 312 showing fluctuations in comparison with daily precipitation totals in June 1995 and January 1996.

Fig. 8. Daily mean stream temperatures at Site 312 showing fluctuations in comparison with mean daily air temperature at CS301 in June 1995 and January 1996.



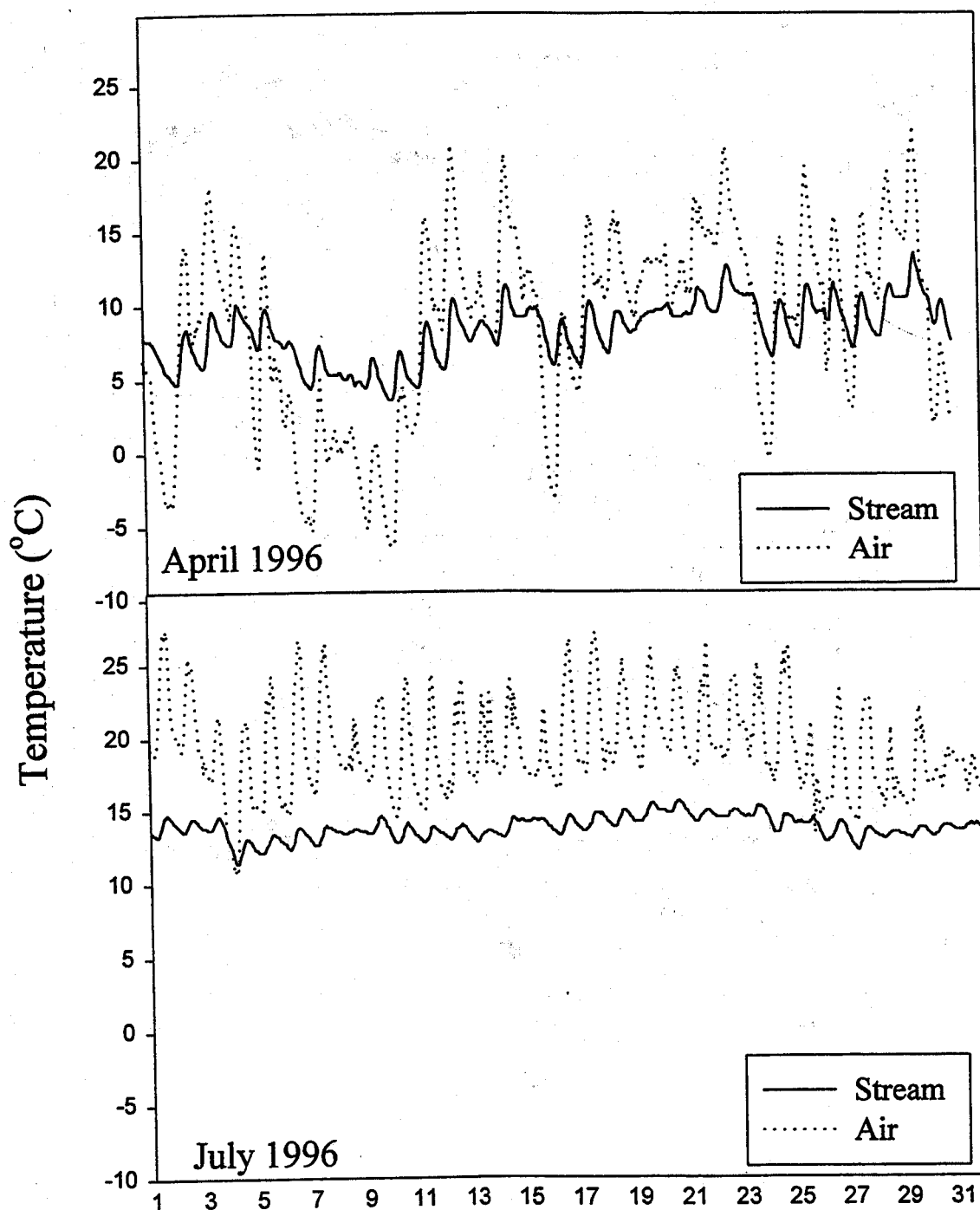


Fig. 9. Diurnal cycles of water temperature at Site 312 and air temperature at CS301 for a variable spring month and a more constant summer month based upon 48-minute (312) and 60-minute (CS301) observations.

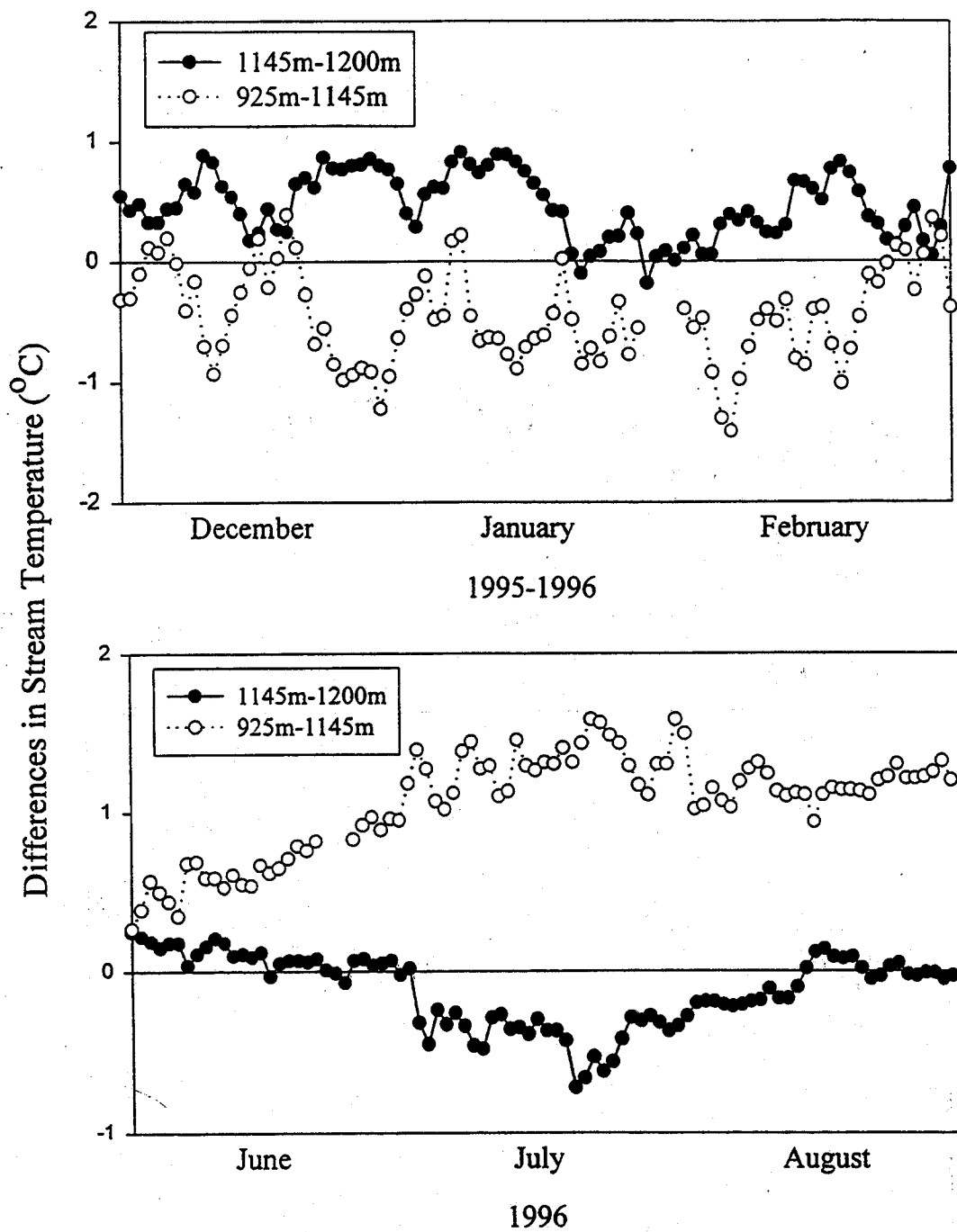


Fig. 10. Effect of elevation upon water temperatures during three winter and three summer months.

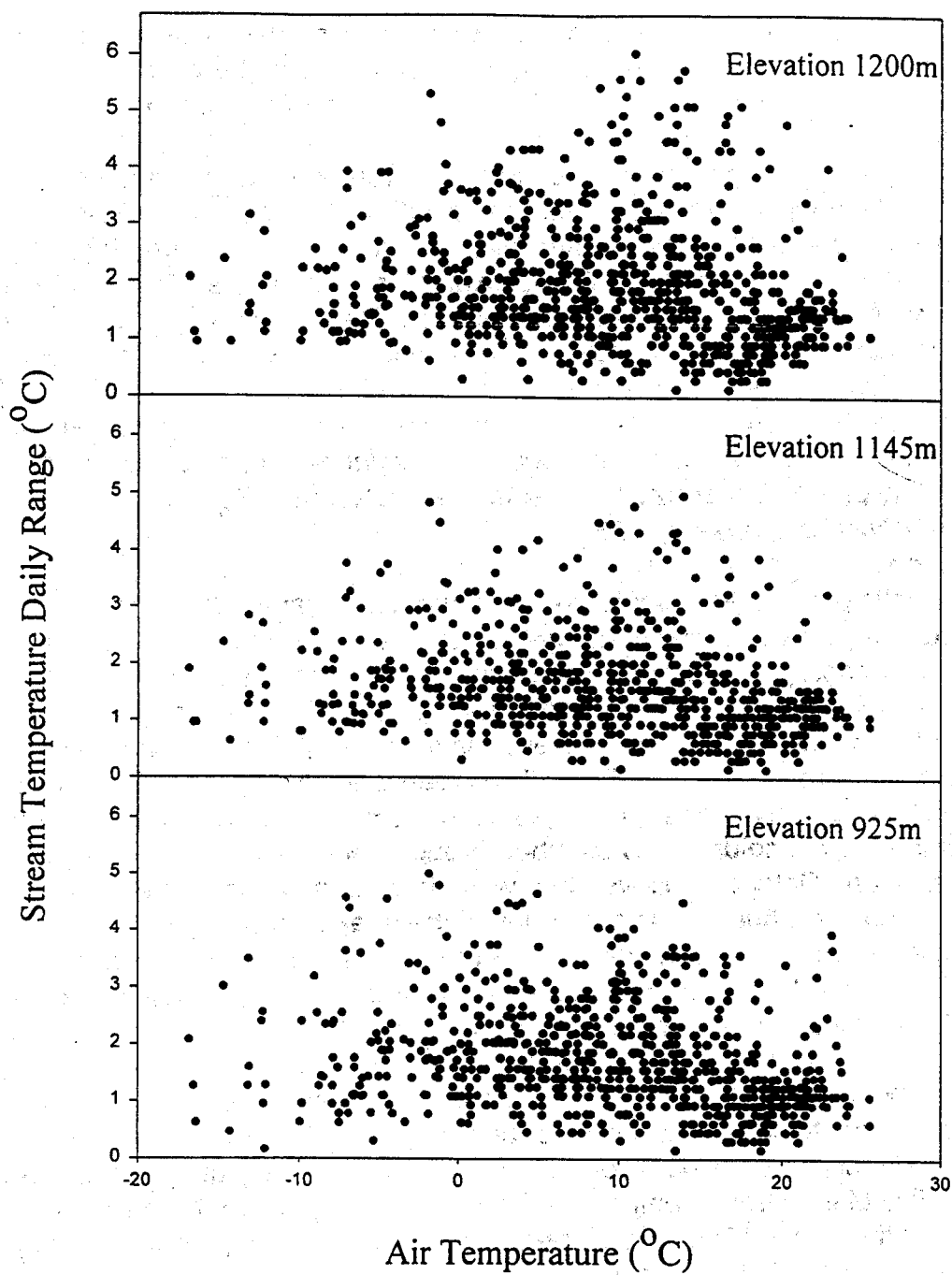


Fig. 11. Effect of season, as represented by air temperature from October 1994 to March 1997, upon daily range of water temperature at three elevations: Site 311 at 1200 m, Site 312 at 1145 m, and Site 316 at 925 m.

swings were wider at the upper elevation where the stream is smaller and had less flow. At all elevations, the smallest daily range was in the warm season; the stream above all three sites was shaded by closed forest canopy in the summer.

Using middle Wine Spring Creek as the reference, the differences between water temperature in the main stream (312) and the two side streams (313, Bearpen and 315, Indian Camp) revealed an apparent topographic response (Fig. 12). Indian Camp Branch water temperature was  $1.0^{\circ}\text{C}$  warmer than the main stream in winter whereas Bearpen Creek was  $0.4^{\circ}\text{C}$  cooler. The difference was smaller and reversed in the summer. For Bearpen and Indian Camp sites, respectively, the mean winter minimums were  $4.2$  and  $5.6^{\circ}\text{C}$  whereas the mean summer maximums were  $14.2$  and  $13.8^{\circ}\text{C}$ . Fig. 1 shows that Indian Camp watershed had a dominance of southfacing slopes compared to Bearpen and probably received more solar heating of the soils and soil water in the winter (Swift and Knoerr, 1973).

### **Conclusions**

Aquatic plants and animals live in a water temperature environment subjected to repetitive diurnal and seasonal cycles that are modified by climatic events and topographic position. The temperature of the stream habitat of Wine Spring Creek watershed in the Southern Appalachian Mountains ranged from near  $1$  to  $16^{\circ}\text{C}$ . Most winter daily means ran from  $2$  to  $7^{\circ}\text{C}$  while summer daily mean temperatures were  $13$  to  $15^{\circ}\text{C}$ . The mean daily minimums or maximums averaged across all five streams suggested four seasons, based on the extreme water temperatures: coldest in December through February, moderate in March through May and October to November, warm in June and September, and warmest in July and August. The duration of the peak annual high or low temperature episodes were usually 3 days or less. The high and low points of the diurnal cycles showed short duration of 60 minutes or less. Daily ranges and day-to-day variation in water temperatures were small in summer, compared to the fluctuations occurring in the leafless seasons. Daily range of maximum minus minimum reached  $5^{\circ}\text{C}$  during March and April when both daytime warming and nighttime cooling were not blocked by full forest canopies. Most summer daily ranges were between  $0.0$  and  $1.5^{\circ}\text{C}$ . The daily ranges described the variability of the stream temperature habitat and suggested three seasons, based upon the stress of diurnal temperature swings: wide daily ranges of  $2$  to  $3^{\circ}\text{C}$  mean for all sites in March and April, small daily ranges averaging about  $1^{\circ}\text{C}$  for June through September, and all other months intermediate at  $1.4$  to  $1.8^{\circ}\text{C}$  daily ranges for all sites.

The diurnal cycle of water temperature was interrupted on heavily overcast days. Precipitation added to the streamflow seemed to have less impact on stream temperature than did the change in air temperature that

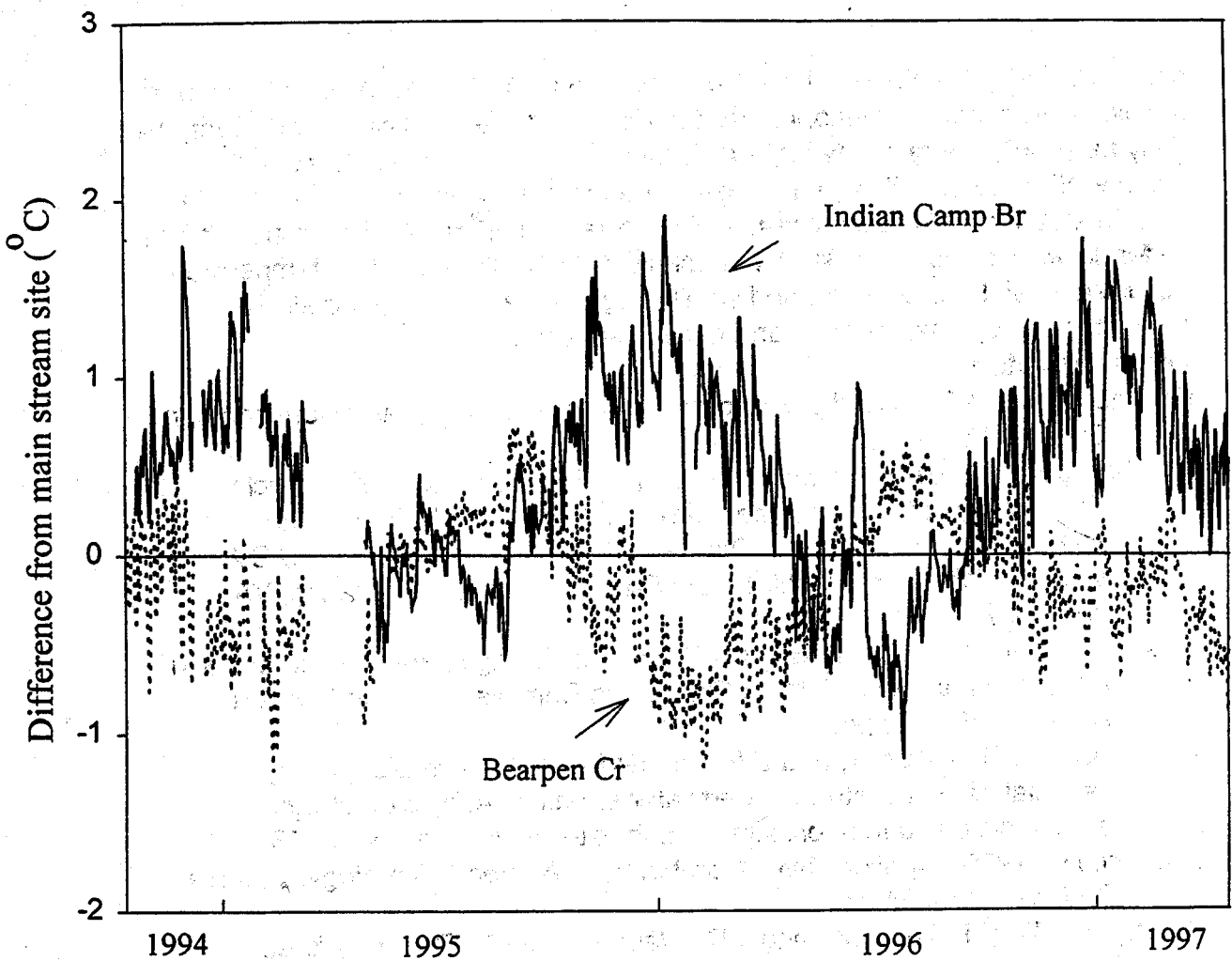


Fig. 12. Effect of landform on water temperatures for two watersheds in Wine Spring Creek basin. Bearpen Creek (Site 313) has a large northfacing component whereas Indian Camp Creek (Site 315) has a large southfacing component.

accompanied most storms. Day-to-day fluctuations of water temperature were smaller than either diurnal or climatic changes in air temperature. However, the daily range is greater at the higher elevation site on a smaller stream. In summer, the mean daily water temperature increased about 0.4 °C per 100 m drop in elevation. At other times, temperature was unchanged or decreased as water flowed downslope. Small but consistent increases in water temperature occurred in winter in a watershed containing a larger south facing slope characterized by shallow soils and more open canopy.

#### **Literature Cited**

- Greene, G. E., 1950. Land use and trout streams. *J. Soil Water Conservation*, 5: 125-126.
- Harshbarger, T. , 1978. Factors affecting regional trout stream productivity. In: *Proceedings of the Southeastern Trout Resource: Ecology and Management Symposium*, October 24-25 at Blacksburg, VA, U.S.A. Virginia Polytechnic Institute and State University, Blacksburg, VA, pp. 11-27.
- Hassler, W. W. and Tebo, L. B., Jr., 1958. Fish management investigations in trout streams. N.C. Wildlife Resources Commission, Fish Division, Raleigh, NC, 118 pp.
- Peters, G.T., J.R. Webster, and E.F. Benfield, 1987. Microbial activity associated with seston in headwater streams: effects of nitrogen, phosphorus and temperature. *Freshwater Biology*, 18: 405-413.
- Rosgen, D., 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO, 384 pp.
- Stout, B.M., III, E.F. Benfield, and J.R. Webster, 1993. Effects of forest disturbance on shredder production in southern Appalachian headwater streams. *Freshwater Biology*, 29: 59-69.
- Swift, L.W., Jr., 1983. Duration of stream temperature increases following forest cutting in the Southern Appalachian Mountains. In: A. I. Johnson and R. A. Clark (Editors), *Proceedings of the International Symposium on Hydrology*, June 13-17, 1982 at Denver, CO, U.S.A. American Water Resource Assoc., pp. 273-275.
- Swift, L.W., Jr. and Baker, S. E., 1973. Lower water temperatures within a streamside buffer strip. Res. Note SE-193. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Asheville, NC, U.S.A., 7 pp.
- Swift, L.W., Jr. and Knoerr, K.R. 1973. Estimating solar radiation on mountain slopes. *Agricultural Meteorology* 12: 329-336.
- Swift, L. W., Jr. and Messer, J., 1971. Forest cuttings raise temperatures of small streams in the southern Appalachians. *J. Soil Water Conservation*, 26: 111-116.

Tank, J.L., J.R. Webster, and E.F. Benfield, 1993. Microbial respiration on decaying leaves and sticks along an elevational gradient of a southern Appalachian stream. *Journal of the North American Benthological Society*, 12: 394-405.

Webster, J.R., and J.B. Waide, 1982. Effects of forest clearcutting on leaf breakdown in a southern Appalachian stream. *Freshwat. Biol.*, 12: 331-343.